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SIMPLE METHODS

OF

TESTING SEWAGE EFFLUENTS

FOR

WORKS MANAGERS, SURVEYORS, &c.

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TESTING SEWAGE EFFLUENTS

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WORKS MANAGERS, SURVEYORS, &c.,

BY

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PREFACE.

THE following little work has been written, by request, to aid Borough Engineers, Surveyors, Managers of Sewage Works, and others not having received a chemical training, in following intelligently the operations connected with sewage purification under their control It is not written for chemists, but for laymen and will, I trust, prove of value to those for whom it is primarily intended.

G. T

Westminster,

October, 1904.

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SIMPLE METHODS OF TESTING SEWAGE EFFLUENTS.

INTRODUCTION.

WITH the large increase that has taken place in the number of sewage works, and the great advance in the methods of purification, accompanied naturally by demands from river authorities for a better class of effluent than was formerly permitted, there has arisen the question: How may the operations be so observed and controlled as to maintain constantly a high standard of efficiency? The ideal solution, of course, would be for each and every works to have added to its staff a skilled chemist, who should make continual examinations and analyses, and direct operations accordingly. This solution will probably be arrived at eventually in the case of the larger cities, but where small installations are to be dealt with its cost would be prohibitive. The alternative is to so instruct the works manager (who, owing to the necessity for his mechanical and engineering knowledge, can never be supplanted by the chemist) as to enable him to form a fair judgment, by simple methods, of the efficiency of his plant; and the following pages are intended as a contribution in that direction.

It may be premised that no methods applicable to so-called "chemical effluents" will be given. The vast strides made in the knowledge of this question during the past ten years have rendered the direct discharge into a stream of an effluent of this class extremely rare, the final effluent being almost invariably produced by biological agency, either through land or in prepared beds. The difference between effluents produced by chemical and by bacterial means may perhaps be usefully discussed. When precipitants such as lime, sulphate of iron, sulphate of alumina, or any of the numerous patent articles once employed, are added to sewage, the principal, and in many cases the only, result attained is the separation of the suspended solids; the action upon the dissolved impurities is always small, and in many cases practically nil. An effluent produced by these means, therefore, will, on analysis, differ but little from the original sewage, if the latter be filtered through paper. The dissolved organic matter will be hardly affected, and no signs of nitrification will, as a rule, be found. But in the case of a bacterially produced effluent, quite different conditions will be observed. The suspended solids will be removed, as in the first case; but they will not have to be collected for ultimate disposal otherwise, but will, in great measure, be absolutely destroyed. In addition to this, great changes will have taken place in the condition of the matters in solution. Even in the effluent from a septic tank it will be found that a large amount of oxidation will have been effected, and in the final effluent from a bacteria bed this will have reduced the readily oxidisable organic matter by some 80-90 per cent. Instead of a high ammonia, both saline and albuminoid, there will be found very little ammonia in either form and considerable quantities of nitric acid.

There is one class of effluent regarding which a special word of warning is necessary, viz., an effluent which has been sterilised by means of some chemical agent, such as hypochlorous acid. As will be seen later, the behaviour of an effluent on being kept for some time affords, as a rule, most valuable evidence as to its original condition and purity, but a sterilised effluent may keep apparently sweet for a very considerable time, and, nevertheless, be capable of putrefaction when the necessary conditions are provided. The actual purification effected by the treatment may be very slight, but the destruction of the microbes by the agent employed will prevent after-putrefaction until the effect of such agent wears off, or the effluent is sufficiently diluted to prevent its further action. Such effluents are highly dangerous, and works managers must be very careful not to be misled by their behaviour on physical examination.

In determining the quality of an effluent both physical and chemical tests are made use of. Thus we examine it as to its appearance—colour and transparency—its odour, its behaviour on keeping and capacity for supporting life, as of fish; we also determine the amount of putrefactive material which it contains, and the proportion which has been oxidised, and thereby rendered incapable of further harm. Any person can be trained to make the first class of observations; the second class can only be approximated, unless a special training has been undergone. The object of this little book is to show how a surveyor or a works manager can, without special chemical training, best make such determinations as are necessary to enable him to follow intelligently the processes going on at his sewage purification works. It must not be supposed that the layman can entirely supplant the professional chemist. Certain methods of analysis can only be carried out by the trained mind and hand, whilst the power of generalising from observed data is only obtained after a very long and varied experience. It is a fact that, in many cases, the true reading of the figures, and not the obtaining of them by analysis, is by far the more difficult task. The relative importance of the various analytical factors will be dealt with later on, as also the question of forming a judgment from the data as a whole.

Throughout the work, except when dealing with the collection of samples, it will be assumed that sewage effluent and not crude sewage is the subject of examination. If it be desired to test the behaviour of any given crude sewage towards bacterial treatment, probably no better means can be adopted than the employment of Mr. Scott Moncrieff's apparatus, as described by him in his paper on "The Standardising of Sewage," read at the Congress of the Sanitary Institute at Bradford in 1903.

The several points will be dealt with in the following order :—

1. The method of taking samples.
2. The examination for transparency, colour, odour, and reaction to test paper.
3. The determination, by chemical means, of those constituents which are most important for the object in view.
4. Behaviour on keeping under various conditions ; putrescibility.
5. The reading of an analysis ; the meaning of the figures obtained.
6. Standards.
7. The care of bacterial filters.

I.—THE METHOD OF COLLECTING SAMPLES.

In collecting, for the purpose of analysis, samples of sewage and sewage effluent certain precautions must be observed, in order that the samples may truly represent that which they are intended to do. If it be desired, for example, to determine the general nature of a given sewage, it is clear that such a sample must be made up of a number of smaller ones, taken at regular intervals during the twenty-four hours and mixed together. This is generally understood and acted upon; but it is not so fully realised that *the bulk of each such individual sample must be proportionate to the rate of flow of the sewage at the time when the sample is taken.* A moment's thought will make this clear. Supposing the strong mid-day sewage to arrive at the outfall at four times the rate of the weak sewage of the early hours of the morning, it is plain that a mixture of equal bulks would not represent the average of these two; but that if one pint of the weaker kind be taken, four pints of the stronger must be mixed therewith in order to produce a truly representative sample. The same argument, of course, applies to the whole twenty-four hours. There may seem at first to be some difficulty attached to the carrying out of this method, but it is more apparent than real. At most sewage works a gauge can be placed at some convenient spot, and a reading can be made each time a sample is taken. In the case of an installation on the purely aërobic principle, the gauge can be fixed in the common feed to the coarse beds, and in a septic tank plant at the outlet from the tank. Should the fixing and reading of a gauge be attended with too great difficulty, the relative rates of flow during the various hours can be determined with a fair amount of accuracy in the case of a domestic sewage in dry weather by means of a well-known table, showing the hourly variations in rate calculated on the average of a large number of actual observations.

Similar precautions must be observed in the collection of effluent samples, should it be desired to secure an average of the discharge over any prolonged period. In mixing the individual samples together to obtain the bulk sample, they must be well agitated, by stirring or otherwise, in order to ensure that a due proportion of any suspended matters that may be present will be taken.

When it is desired to ascertain the effect of the passage of sewage through a given set of bacteria beds or a septic tank installation, care must be taken that the final effluent sample really corresponds with that of the original sewage. Thus, in the case of a plant on the Sutton principle, the sewage must be sampled, say, every five minutes, as it flows on to the coarse or primary bed (in this case equal volumes may usually be taken); samples must again be taken from the outlet of the coarse bed, the individual samples being proportionate to the rate of emptying; and the same process must be gone through in the case of the fine or secondary bed. This may appear to be a needless refinement, but experience has shown that the quality of a bacteria bed effluent differs considerably during various periods of the discharge, the last drainings, for example, being purer and more highly nitrified than the bulk. It is very difficult to obtain comparable samples from the inlet and outlet of a septic tank, unless the operations are extended over a considerable period of time, as it cannot be supposed that the inflowing sewage acts as a piston, driving the whole contents of the tank before it; a very large amount of mixing necessarily takes place. This is no doubt a great advantage with regard to the action of the bacteria in the tank, but it makes the task of the sampler more difficult. The analyst's main guide in determining whether samples of sewage and effluent are comparable is their chlorine content, this being unaffected by the ordinary methods of purification.

It will be seen from the above that if a reliable result is to be obtained, the manner in which the samples are collected must receive far more attention than is ordinarily given.

The next point to be looked to is the time that elapses between collection and analysis. All samples of sewage and effluent should be delivered to the analyst as quickly as possible; and once arrived in the laboratory, no delay should take place in their examination. The work of the microbes does not cease when an effluent is put into a bottle; a constant action takes place, bringing about changes in the direction of purification, so that even a crude sewage, kept in the laboratory for a couple of months, may appear on analysis to be a good effluent; and effluents in which little or no nitrification had occurred at the time of sampling, will show a large proportion of nitrates on keeping. In fact, standing in the laboratory for any material length of time will affect all the analytical factors except the chlorine.

II. — EXAMINATION FOR COLOUR, ODOUR, &c.

A. Transparency and Colour.

These should always be observed and recorded Such terms as "brilliant," "bright and clear," "clear," "slightly turbid," &c., may be usefully employed, and the presence or absence of visible particles of suspended matter should be noticed, together with their character and colour, *e.g.*, "small quantity, flocculent, dark." This examination should be made in a clear, colourless glass vessel, and through a stratum several inches in thickness or depth. A Nessler cylinder is very useful for the purpose, and if always filled to the same height will cause the records to be comparable one with another. The same vessel will serve to note the colour, which in many cases is of importance. Care must be taken to have a sufficiently deep stratum of liquid; to hold a narrow glass sideways to the light is all very well when showing a visitor what a beautiful effluent is being produced, but for forming a true judgment at least five inches should be looked through.

B. Odour.

A portion of the sample should be placed in a wide-mouthed stoppered bottle, and should be vigorously shaken. On removal of the stopper the bottle should be immediately applied to the nose, and any observation made noted. It is, of course, not intended to apply this method to evidently foul and stinking samples, but its use will frequently enable the operator to detect a slight odour, which would be inappreciable if sought for in an open vessel. High-class bacterial effluents have very frequently an odour which is commonly described as "earthy," closely resembling, indeed, that of newly-turned garden mould. This may be usually taken as an indication that the process of purification has arrived at a satisfactory stage, and that after-putrefaction is unlikely to occur.

C. Reaction.

Most sewages, on being tested with litmus paper, will give an alkaline reaction, the paper becoming more or less blue. This is always the case with purely domestic sewage, as ammonia is rapidly developed from the decomposition of the urea, whilst soap and washing soda also play their parts. Certain manufacturing processes, however, produce refuse liquors which are, or which, by fermentative action, become, highly acid, and the presence of these in sewage in any large proportions will give rise to an acidity of the whole, which is not favourable to microbial purification. The liquor from galvanising or tin-plate works is an example of an acid discharge which certainly renders the treatment of the sewage much more difficult; and examples of trade refuse liquors which develop acidity naturally during the process of decomposition are brewery and distillery wastes. Sewage exhibiting a slight degree of alkalinity is most suitable for treatment by microbial methods; and successful treatment will always produce an effluent which either is neutral—that is to say, neither acid nor alkaline—or is very faintly alkaline.

In making the test care must be taken not to touch with the fingers that portion of the litmus paper upon which the observation is made, and if the liquid to be tested be coloured, the paper must be lightly rinsed with pure water before inspection.

III.—CHEMICAL TESTS.

The analytical data to which the works manager should specially devote his attention are the solids (suspended and dissolved), the amount of oxidisable matter as measured by the oxygen absorbed from permanganate of potash under certain conditions, and the nitrous and nitric nitrogen. A determination of the chlorine will only be necessary when it is desired to make sure that a sample of effluent corresponds with the particular sewage from which it is supposed to be derived. Albuminoid ammonia is, of course, a very valuable guide; but the process requires more technical knowledge and skill, and takes more time than can properly be demanded of a works manager, who has many other things to occupy his attention. Before entering into details of the various processes it may be pointed out that the methods described by Dr. Thresh, in "A Simple Method of Water Analysis," afford an admirable means for the unskilled operator to attain analytical results which, although not absolute, are quite sufficiently accurate for all the purposes of a sewage purification works.

A. Solids, Suspended and Dissolved.

Suspended solids may be divided into two classes:

(1) Sewage matters proper, by which is meant floating particles derived from the living body, as the

ordure of man and horses, and from the refuse of kitchens, &c. This matter, of animal and vegetable origin, contains a certain proportion of mineral substance, obtained as a residue on burning; and as part of this residue is insoluble in water, this part of the suspended matter will be retained to some extent in a septic tank or a primary bacteria bed, and will require removal at intervals more or less prolonged.

(2) Detritus, which is chiefly sand, granite, and clay derived from the surfaces of roads, and which will find its way into the sewers during periods of heavy rain, even with the most perfect system of separate drainage, whilst with a combined sewerage system it becomes a very important factor. In towns where wood paving is largely employed, the fibre worn from the surface has also to be considered and dealt with.

A perfect final effluent should contain no visible suspended matter whatever. It has, however, been observed that where the method of purification is that of continuous sprinkling and percolating through a bed, a certain amount of black, flocculent matter is usually present. This matter appears, however, to be non-putrescible, and may generally be neglected. It is mostly sufficient to merely note its presence, with a qualification such as "much" or "little." A septic tank effluent, on the other hand, always contains suspended solids in a state of very fine sub-division. Should it be desired to ascertain their amount, as, for instance, to see what work is being put upon the secondary bed, the simplest method is to put a measured quantity in a previously weighed dish, evaporate to dryness, and weigh the residue. Repeat the process on another portion of the effluent which has been filtered through paper; the difference in weight between the two residues is that due to the suspended solids. It will be seen that by this method both the suspended and the dissolved matters are determined; if the former only be required, the preliminary weighing of the dish may be neglected.

EXAMPLE I.—100 *c.c. of Effluent Evaporated.*

Dish + total residue	50·081
Dish	50·
Total residue, dissolved and suspended	0·081
Dish + residue from filtered sample	50·069
Dish	50·
Residue from filtered sample, dissolved	0·069

The effluent contained, in each 100,000 parts, 81 parts of total solids, of which 69 were in solution and 12 in suspension.

EXAMPLE II.—100 *c.c of Effluent Evaporated.*

Dish + first residue	50·081
Dish + second residue... ...	50·069
Difference, suspended solids	0·012

The effluent contained, in 100,000 parts, 12 parts of suspended solids. It will be observed that if 100 c.c. be taken for the analysis, the parts per 100,000 can be found from the actual weight of the residue by merely shifting the decimal point three places to the right.

With regard to dissolved solids, the most important matters to note are their appearance and colour when dried and their behaviour on ignition. If crude sewage be evaporated, the residue will be highly coloured, will swell and blacken on ignition, and will give off a very offensive odour of burnt urine. A first-class effluent, similarly treated, will leave an effluent that is practically colourless, darkens more or less on ignition, and gives no burnt urine odour. The more nearly an effluent answers to these requirements, the better. The operator requires only a nickel dish, a water bath, and a Bunsen gas burner or a spirit lamp. The indications given are of considerable value. They would, for example, at once condemn the effluent produced by merely sterilising by an agent such as hypochlorous acid, already alluded to.

B. Oxygen absorbed from Permanganate.

The determination of this factor, unless advantage be taken of Dr. Thresh's method of soloids, requires considerable knowledge and practice. The object is, by ascertaining how much oxygen is abstracted in a given time from permanganate of potash, present in excess, to obtain a measure of the more readily oxidisable matters remaining in the effluent. The reagents required are :—

Standard permanganate solution.
Dilute sulphuric acid.
Sodium thiosulphate ("hypo") solution.
Potassium iodide.
Starch solution.

The standard permanganate solution should be of such a strength that one cubic centimetre equals one milligramme (one-thousandth part of a gramme) of available oxygen. It is best purchased ready prepared from one of the chemical firms dealing in standard solutions, but if required to be made on the works, dissolve 3·95 grammes of pure permanganate crystals in one litre of pure distilled water.

The dilute sulphuric acid should contain one part by volume of pure acid to three parts of distilled water. Those unaccustomed to handle such materials may be warned that the acid must be poured into the water, and not on any account the water into the acid. When mixed, add a little of the permanganate solution until a very faint pink tinge remains permanently.

The hypo solution is made by dissolving 10 grammes of crystallised hypo in one litre of pure distilled water.

To prepare the starch solution stir a small quantity of starch well with distilled water (say, one gramme of starch to 250 cubic centimetres of water), and boil briskly for ten minutes. Allow to settle, and pour off the clear liquid for use.

The analysis is made as follows :—Into a clean stoppered bottle, having a capacity of about 200 c.c., put a measured quantity of the effluent, varying, according to its degree of purity, from 10 c.c. to 50 c.c., and make up to about 100 c.c. with distilled water. Then add from a pipette 10 c.c. of the dilute sulphuric acid, and, finally, 10 c.c. of standard permanganate. Place the bottle in a temperature of about 80 deg. Fah., and examine it occasionally. Should the red colour disappear, add another 10 c.c. of permanganate. After four hours, when the red coloration must be still quite distinct, remove from the warm chamber or spot, add a crystal of iodide, and shake gently, when the pink will immediately change to a yellow, owing to the liberation of iodine by the permanganate and its solution in the excess of iodide. Then, from a burette, add hypo solution very gradually, shaking constantly, until the yellow colour almost disappears. Then add a few drops of starch solution, when a blue tint will be at once developed, and continue the cautious addition of hypo until no colour whatever remains. Read off from the burette the quantity of hypo that has been required to effect this, and note it. Perform a precisely similar series of operations with another bottle, in which 100 c.c. of distilled water were placed originally, and no effluent. This will give the relative values of the permanganate and the hypo. Thus:—

First bottle: 50 c.c. effluent + 50 c.c. water + 10 c.c. dilute acid + 10 c.c. permanganate + iodide + starch required (say) 6 c.c. hypo.

Second bottle: 100 c.c. water + 10 c.c. dilute acid + 10 c.c. permanganate + iodide + starch required (say) 11 c.c. hypo.

Eleven c.c. hypo corresponded with 10 c.c. permanganate, or with 0·01 gramme available oxygen; therefore each c.c. hypo equalled 0·0009 oxygen. In the first bottle 6 c.c. hypo were required: therefore 11 less 6, or 5 c.c., represents the hypo corresponding to the quantity of available oxygen absorbed by the effluent, equal to 0·0045 gramme, or 0·9 part per 100,000 parts.

It will probably be much simpler for the layman to use Dr. Thresh's soloids. The reagents required are soloids of permanganate, each representing one milligramme of available oxygen; soloids of oxalic acid, each capable of exactly decolourising one soloid of the permanganate; and soloids of acid sulphate of sodium. The acid sulphate is first added to the effluent under examination, then the permanganate, and the bottle is kept at a temperature of about 80 deg. Fah. for four hours as before, an additional solid of permanganate being added should the red colour nearly disappear. At the expiration of the four hours a soloid of oxalic acid is added, and the whole warmed gently; should any colour or brown deposit remain, an extra soloid of oxalic acid must be added, and the solution warmed until quite clear and colourless. Then dissolve a soloid of permanganate in 10 c.c. of water, and add it drop by drop until a faint pink colour appears. The permanganate destroyed by the effluent will be that added originally (and that during the four hours, if any), less the quantity required to just restore the pink coloration.*

C.—Nitrous and Nitric Acids.

The presence of a considerable proportion of fully oxidised nitrogen, *i.e.*, in the form of nitric acid, is after all the great test of the quality of a sewage effluent. If nitrates be high and unoxidised organic matters low, the effluent may fairly be pronounced satisfactory. Expressed in another way, the ratio of oxidised to unoxidised nitrogen is the measure of the purification that has been effected.

It is not always necessary for a works manager to determine the actual quantities of nitrous and nitric acids ; it is sufficient as a rule if he demonstrate their presence, using a qualifying term, such as trace, little, considerable, very much. This he may do very easily. The reagents needed are dilute sulphuric acid and starch solution, both prepared as described above ; iodide of potassium, and zinc dust. Fill a Nessler cylinder to the mark with the effluent ; add a few drops of acid and a crystal of iodide, and then a little starch solution. A blue coloration indicates the presence of nitrous acid, the depth of tint depending on the quantity. If no colour be produced in five minutes, no nitrites are present. Take a second portion of effluent, add acid, iodide and starch as before, and also a little zinc dust. Stir and allow to settle. Any nitrates present will be reduced to nitrites, and additional blue colour will be produced, its depth and the speed of its production being proportional to the amount. Or some of the effluent may be boiled with a few drops of the acid until the bulk is reduced by one-half, when it can be made up to its original volume and be treated with zinc, iodide, and starch as before. Any blue colour is, in this case, due only to nitrites produced by reduction from nitrates, the boiling with acid driving off any pre-existing nitrous acid. If it be desired to ascertain the actual amount of nitrous and nitric acids present, it can be done by using, for comparison, water containing known quantities, altering these quantities until the depth of colour produced fairly matches that observed with the effluent. This will be quite sufficiently accurate for the purpose intended.

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* Thresh. "A Simple Method of Water Analysis." 1898. Second edition, pp. 48-49.

Care must be taken in all operations in which starch solution is employed that it has not been kept too long; it is best to make it fresh every few days.

Should a manager require an accurate estimation of the nitrous and nitric acids, he must use a process occupying more time and making more claims upon his knowledge. Nitrous acid is best determined by comparing the depth of colour produced on adding dilute sulphuric acid and metaphenylene-diamine to the effluent, with that produced by the same reagents in a solution of nitrite of known strength, varying the latter until the tints are identical. Place 100 c.c. of the effluent in a Nessler cylinder, and add 1 c.c. each of the dilute sulphuric acid and metaphenylene-diamine. If the colour appears too quickly, dilute with pure water, and try again. In another cylinder, take pure water with a measured quantity of a standard solution of nitrite, add the reagents, and compare with the first cylinder. If the brown colour in the comparison cylinder be too light, add a little more standard nitrite ; if too dark, prepare another, containing less nitrite. When the colours in the two cylinders, after standing about a quarter of an hour, are identical, the quantities of nitrite in each are equal. The nitric acid may be determined by the indigo method. To 25 c.c. of effluent add 50 c.c. of pure concentrated sulphuric acid, taking care to do this in a thin flask and over a sink, in case of breakage, as a great heat is developed. Whilst quite hot, add gradually some indigo solution (which had better be obtained ready prepared), shaking the while until it is no longer decolorised, but a faint blue remains permanently. The value of each cubic centimetre in terms of nitrogen is ascertained by repeating the process, using, instead of the effluent, water to which has been added a known quantity of standard nitrate solution. This process gives both the nitrous and nitric acids ; the former, therefore, as found by the metaphenylene-diamine method, must be deducted, when the remainder will be the nitric acid. It must be understood that the indigo method as given above is only roughly that employed by chemists ; in the laboratory precautions are taken to ensure accuracy which may be deemed unnecessary on a sewage works. Anyone desirous of studying the process fully will find all details in Sutton's work on "Volumetric Analysis."

D.—Chlorine.

In cases where an analysis is made of an effluent or effluents derived, or supposed to be derived, from a particular sewage, the chlorine content shows whether the samples are really comparable or no, since it is unchanged in amount by the purifying processes.

It is determined as follows:—A known quantity of sewage or effluent is placed in a white porcelain dish, and is diluted, if necessary, with distilled water. Yellow chromate of potassium is then added in sufficient amount to give the whole a distinct yellow tinge. A solution of nitrate of silver of known strength is added drop by drop from a burette, stirring constantly, until a faint tinge of red appears, due to the silver uniting with the chromic acid, having exhausted the available chlorine. The exact point at which this change takes place will only be accurately observed after considerable practice.

Example:—100 c.c. of sewage were found to require 8·4 c.c. of silver solution, of which 1 c.c. is equivalent to 0·001 gramme chlorine. Then 100 c.c. sewage contain 0·0084 gramme chlorine, equal to 8·4 parts per 100,000.

It occasionally happens that the chlorine is the last factor to be determined in a sewage, owing to the fact that it remains unchanged, whilst other matters must be looked for at once. It may, therefore, happen that the sewage becomes putrid before the analysis for chlorine is made, in which case the sulphuretted hydrogen which is usually developed will interfere with the reaction. This may be remedied by shaking the sewage with a little carbonate of lead and filtering, when the sulphuretted hydrogen will be removed. Any considerable degree of either alkalinity or acidity will also obscure the reaction.

IV.—BEHAVIOUR ON KEEPING.

The most important character for an effluent to possess is, that it should be incapable of putrefying under any reasonable conditions. Such a character is proof at once of great purification having been effected, and of impossibility of producing a nuisance in a stream into which it may be discharged. It is in this particular that good bacterial effluents—amongst which are, of course, included those from sewage farms—exhibit such a great advantage over effluents produced by chemical precipitation. If any general standard of purity were ever adopted, certainly one of the first requirements should be that no effluent would be passed as satisfactory unless it showed no signs of putrefaction on being kept for a number of days in a closed vessel at a temperature of 80 deg. Fah. A high-class filtrate does not develop the slightest offensive smell under such conditions; on the contrary, the faint, earthy odour, which is frequently present when the sample is first collected, disappears, and no smell at all can be detected. Here again care must be taken that the effluent is not one of those, already alluded to, produced by sterilisation. I have known many effluents, in the days of precipitation, which would apparently answer this test, owing to, for instance, their containing a very large excess of lime. But, on dilution, these always putrefied.

This very simple test is one of the best that can be applied, and it may be kept in constant operation by having a sufficient number of bottles to hold the samples collected during seven days, each new sample being placed in the bottle which previously contained the oldest on the list, and the whole being examined at a fixed hour each day. A set of bottles, marked with the names of the several days of the week, may be assigned to the effluent from each final filter; such a proceeding yields a very valuable record of the working of the whole plant. But the examination must be made daily on each of the seven bottles, or its value is greatly diminished.

Mr. Frank Scudder, the chemist to the Mersey and Irwell Joint Committee, has devised a method by which the liability to putrefy, or the degree of change which actually takes place, can be determined by a chemical process and be recorded in figures. This process is based on the fact that substances such as sulphuretted hydrogen, which are very rapidly oxidised by permanganate, are produced during putrefaction, and therefore an increase in the amount of oxygen rapidly absorbed indicates that to some extent putrefaction has occurred. The method employed by Mr. Scudder is to determine the amount of oxygen absorbed from permanganate in three minutes, and then to place in an incubator, kept at 75 deg. Fah., a small stoppered bottle, completely filled with the effluent under examination, and leave it for five days. At the expiration of this period the three minutes' absorption is again determined, and compared with the figure first obtained. Speaking generally, any increase in the amount of oxygen required indicates putrefaction, the extent of the increase being some index of the degree of the putrefactive change; a good effluent will show either no alteration or a more or less marked reduction. Care must be taken to ascertain that the increase in oxygen absorbed, should any be found, is not due to nitrites, which may have been formed by the reduction of nitrates during the process of incubation. As a rule however, if nitrates be present to any marked extent, the purification effected is sufficient to make after-putrefaction impossible. I consider this method of Mr. Scudder's as most valuable, providing, as it does, an actual record in figures of the exact condition of the filtrates with regard to putrescibility.

Another very useful point to observe is the behaviour of an effluent with regard to its absorption of air-derived oxygen dissolved in it. A clean river water under natural conditions always holds in solution a certain quantity of oxygen, dissolved by it from the atmosphere, the quantity varying only according to and inversely with the temperature. It is by this dissolved oxygen that fish life is maintained, and when the fish in a river disappear, owing to the water having become polluted, it is generally not from any direct poison being introduced, but from the reduction of the quantity of free oxygen to an amount too small to enable the respiratory process to continue, and the fish are simply suffocated. In water containing much organic matter the oxygen is used by the micro-organisms in oxidising the pollutive substances, in greater ratio than it can be supplied by re-absorption from the atmosphere. In sewage, for example, the demand so far exceeds the supply that there is practically no free oxygen present, and if it be introduced by artificial means, as by violent agitation, it quickly disappears again. The rate at which water can take up oxygen from the air varies with its degree of aëration; the more it already contains, the more slowly it takes up further quantities, whilst when nearly depleted of air, it absorbs it with great avidity. Given, then, a plentiful supply of oxygen, such as is yielded by the air in contact with the surface of a river, and a degree of aëration will be found to exist fairly constantly, fixed by the balance arrived at between the rate at which oxygen is consumed and that at which it can be re-absorbed. It is evident, then, that the condition of an effluent with regard to organic matter may be determined by estimating the quantity of oxygen dissolved in it, and the rate at which that oxygen is diminished under given conditions. The methods, however, by which dissolved oxygen can be determined do not readily lend themselves to employment by unskilled hands, but the works manager can always avail himself of the supreme test, namely, the capability of the effluent to support fish life. Let a few ordinary goldfish be kept in a globe or aquarium, using only effluent as water supply. Draw off each morning, by means of a syphon, the greater part of the water, and replace by an equal quantity of the day's sample, which has been well shaken. If the fish live, and show no signs of distress, the effluent is undoubtedly sufficiently aërated. It must not be forgotten that goldfish, like other animals, require feeding occasionally.

V.—MEANING OF RESULTS OF ANALYSIS.

When sewage is purified, the organic matters contained in it undergo certain changes, which are only complete when the whole of the carbon, hydrogen, and nitrogen originally present are combined with the maximum amount of oxygen which they are capable of taking up, or are dissipated, in the case, anyhow, of the third-named element, in the free state in gaseous form. We start with substances containing the above-mentioned elements in what is known as organic combination—such substances as gelatine, for example ; and we finish, theoretically, with all the carbon as carbonic acid, all the hydrogen as water, and all the nitrogen as nitric acid, which are no longer classed as organic substances, but are called inorganic or mineral. Let us follow this out in the case of the well-known substance urea. Urea, which is an important constituent of urine, contains all the four elements named above—carbon, hydrogen, nitrogen, and oxygen combined in one organic whole. It is rapidly acted upon by certain definite micro-organisms, with the result that it combines with water and forms ammonia and carbonic acid, which unite to form carbonate of ammonium. By the action of other classes of organisms, under suitable conditions, this is split up and oxidised so as to produce carbonic acid, water, and nitric acid. Oxidation is then complete, and no further change takes place.

The object of the analysis of sewage and effluents is to enable us to follow the various steps of these changes and determine the point at which they have arrived. Let us take, as an example, the gelatine already referred to. When fresh, we should obtain little or no ammonia by distillation alone, but would have a copious yield of so-called albuminoid ammonia on distillation with permanganate and caustic potash. There would also be a high figure for oxygen absorbed from permanganate in four hours, but a very low result in the five minutes' test. From these results we are able to argue the presence of a quantity of nitrogenous organic matter, capable of putrefaction and of producing nuisance at some future time, but at present fresh, and with the changes towards purification not commenced. If the solution be examined after a few days, we should first notice a turbidity and an offensive odour; free ammonia would be evolved on simple distillation; the albuminoid ammonia would be less; and the four hours' oxygen absorbed would be to some extent diminished, whilst that taken up in five minutes would be increased. Putrefaction is in progress, and the nitrogen has commenced its journey towards nitric acid by forming ammonia; the total oxygen absorbed is lowered, because some oxidation has already taken place naturally; the oxygen required in five minutes is increased, because the putrefactive change renders the substance more easily and quickly attacked. This is the essence of Scudder's incubation test, already described. Suppose we now supply the putrid solution with the conditions necessary for final bacterial oxidation. We shall find, on analysing afterwards, that very little ammonia, either saline or albuminoid, can be obtained; that the oxygen absorbed in five minutes is practically nil, and that absorbed in four hours is reduced to a small fraction of the original amount. In addition to this, new substances will now have made their appearance, namely, nitrites and nitrates. From this analysis we learn that putrefaction has finished and oxidation succeeded it; that the nitrogen of the organic matter is now mainly in inorganic combination, and therefore incapable of producing nuisance in the future; and that the carbon has been oxidised by microbial action, and no longer attacks the permanganate.

The following little table will show how these considerations apply to sewage at various stages of its decomposition. It is, of course, not possible to make the first analysis on absolutely fresh substances; the urea, for instance, will be already decomposed by the time the sewage reaches the works, and there will be considerable development of free ammonia. The changes also are very complicated and overlapping. The general idea, however, shows quite clearly. The figures given are taken practically at random from a report on the septic tank experiments at Manchester, and are selected merely as typically illustrating what has been said above.

—	Parts per 100,000.			
	Ammonia.		Oxygen absorbed in 4 hours.	Nitric nitrogen.
	Free.	Albuminoid.		
Crude sewage...	3·44	0·886	11·09	—
Tank effluent ...	3·53	0·420	7·00	—
Filtrate	1·61	0·197	1·97	0·75

This is not a very favourable example of a final filtrate, as the oxidation is hardly carried sufficiently far, although the sample stood the incubator test and was not putrescent; but the steps of the process are well shown. First, there is a high ammonia, both saline and albuminoid, and a very high oxygen absorbed. As a result of the anaërobic changes the saline ammonia is slightly increased, and the albuminoid ammonia reduced by over one half, whilst the oxygen absorbed is considerably lowered. In the filtrate both forms of ammonia are again less by more than 50 per cent., and the oxygen absorbed by over 70 per cent., whilst a considerable quantity of nitric acid has been produced.

In this, then, lies the value of analysis. It tells us not only that there is or was a certain quantity of organic matter present, but also to some extent the stage which has been reached in the decomposition of that matter. That is the meaning of the importance laid upon the factors usually selected for analysis. By using particular methods, we can determine in the form of ammonia, both the albuminoid nitrogen and the nitric nitrogen. The nitrogen is the same, that in the nitric acid being derived from that originally present in the albuminous matter, but it is in a different form of combination, and analysis discloses this. Where we find much albuminoid nitrogen, we know we have a source of potential nuisance ; that is to say, given the necessary conditions, and putrefaction will follow. When, on the other hand, in a liquid originally yielding much albuminoid nitrogen, we find considerable quantities of nitric acid, we know that the natural changes have proceeded to the necessary extent, and decomposition and oxidisation are either completed, or will become so without the development of any unpleasant or dangerous accompaniments.

In following the course of oxidation of the carbonaceous matters, we have to be content with simply noting the decrease in the quantity of oxygen absorbed from permanganate, as the ultimate product, carbonic acid, escapes in the form of gas, and does not, like the nitrogen, leave some proportion behind in a form in which it can be estimated. But the oxygen-absorbed factor is in itself sufficient, although the proof is only of a negative description.

It will be seen from the above that the actual figures obtained in an analysis of an effluent are, in great part, of lesser importance as compared with the comparisons which can be instituted between them and the figures relating to the original sewage and between themselves. Thus, in the example given in the table above, the filtrate yields actually as much saline and albuminoid ammonia, and absorbs as much oxygen from permanganate as do many samples of weak, crude sewage. But the presence of the nitrate in such quantity tells us that this is a filtrate and not a sewage, and a comparison with the original figures shows that such an alteration has taken place in the direction of purification that further putrefaction is not to be feared, whilst a sewage yielding the same quantities of ammonia, but from substances in a different stage of decomposition, would inevitably putrefy.

VI.—STANDARDS.

The question of standards is one that deeply concerns the managers of sewage works, as, should any be generally adopted, it would be their duty to see that their effluent regularly conformed to its requirements. It would therefore appear that a first necessity of any standard is that it should be of a nature admitting of its constant application on the works themselves, and not need the services of a trained chemist. The man on the spot, who superintends the working of the plant, should be able to satisfy himself that the impurities in his effluent do not exceed the limits which may be fixed by law. This I regard as all important. No periodical analyses by the borough analyst, or occasional examinations by the selected expert, can possibly equal in value the daily observations of the works manager, if he be given a weapon which he is able to use, and if he act according to the results found.

If this contention be sound, then many proposed standards are at once placed out of court. Such as are based on albuminoid ammonia, for example, or on actual numerical ratio of oxidised to unoxidised nitrogen, or on the rate of consumption of oxygen from fully aërated water, will not be of practical value from this point of view. It will, however, be interesting to review some of the many suggestions that have been made before attempting to formulate one that will satisfy the trained chemist and yet be easily operated by the layman. And it might also be of value to consider the question as to whether any fixed general standard is desirable, or whether each locality should have its own.

Dealing with the latter question first, it certainly appears that considerations of locality and relative volumes must always be brought into the calculation; it would be absurd, for example, to demand of London, discharging its sewage into the Thames at a point below which potable water could never, under any circumstances, be drawn; it would be absurd to demand a degree of purification which would quite properly be required of Oxford or Reading, the sewage of which passes into a river which is, later in its course, the source of the water supply of some millions of people, besides being a public playground. There are cases, again, in which practically the whole flow of a small watercourse, during the summer months, is due to the sewage effluent from some village or town on its banks; and clearly, in such cases, a higher standard of purity must be sought than is necessary when the volume of pure, aërated water, relative to that of the sewage effluent, is very large. It would appear, then, that whilst a general standard may possibly be regarded as inadvisable, as it would either press unduly hard in some cases or give an opening for possible pollution, and consequent nuisance in others, yet local standards might be adopted with advantage.

The most elaborate standard which has ever been devised is that suggested by the Rivers Pollution Commissioners. Put briefly, it advised that no liquid should be considered as admissible (into a stream) which—

(*a*) Contains in suspension more than three parts, by weight, of dry mineral matter, or more than one part, by weight, of dry organic matter in 100,000 parts, by weight, of the liquid.

(*b*) Contains, in solution, more than two parts, by weight, of organic carbon, or 0·3 parts of organic nitrogen in 100,000 parts.

(*c*) Exhibits, by daylight, a distinct colour in a stratum one inch deep in a porcelain vessel.

(*d*) Contains, in solution, in 100,000 parts more than two parts of any metal, except calcium, magnesium, potassium, and sodium,

and six other provisions relating to arsenic, free chlorine, sulphuretted hydrogen and soluble sulphides, acidity, alkalinity, and petroleum or hydrocarbon oils.

Such an elaborate standard carries its own condemnation. The determination of organic carbon and nitrogen is a long and laborious process, and can only be undertaken by specially trained persons. It is quite evident that this standard will not meet the requirement, that it can be applied by the works manager, and that continuously.

Some authorities have adopted as a standard a maximum permissible amount of albuminoid ammonia and oxygen absorbed from permanganate, the actual figures varying slightly in different localities. These standards again fail when tested by the suggested criterion that they should be capable of continuous application by the manager. He would have to spend his whole day before his ammonia retorts. A further objection is that only the quantity and not the condition of the organic matter is shown.

The ratio of oxidised to unoxidised nitrogen undoubtedly affords absolute proof of the condition of an effluent, and there would be no need to seek further for a standard could analytical methods be devised which would be at once simple, quick, and accurate. But whilst the first factor can be determined, with sufficient accuracy for the purpose, easily and in a very short time, the second, even for an approximation, demands considerable time and attention.

The determination of the quantity of oxygen abstracted in a given time from a fixed proportion of fully aërated water gives very valuable indications regarding the quality of an effluent, but it can only be made by a chemist. A similar objection attaches to the use, as a standard, of the rate of absorbing atmospheric oxygen under any given conditions.

Most authorities are agreed that the presence of nitrates in considerable amounts is a fair guarantee of the quality of the effluent. The actual proportion desirable may be determined by either of two ratios: (1) Total oxidised to total unoxidised nitrogen; or (2) available oxygen in the nitrate to oxygen required, as measured by that absorbed from permanganate. As has already been pointed out, the determination of the unoxidised nitrogen needs much skill and time; the oxygen absorbed from permanganate does not actually take up much time, but the figures are only available after four hours of waiting. Yet by either of these means a safe guide can be assured. Is it possible, then, to use such a standard without putting too much work, as an extra, upon the shoulders of the manager? I believe it is.

Examination of published analyses of sewage and effluents shows that in most cases in which the effluent is pronounced to be satisfactory, or even only fair, the nitrous and nitric nitrogen in the effluent, taken together, exceed the albuminoid nitrogen (measured by the albuminoid ammonia process) in the original sewage. The albuminoid nitrogen is a factor that is fairly constant, day in and day out, in most sewages: it varies, of course, considerably during the day, but the daily averages vary only very little, under similar conditions of weather. A standard might, therefore, be adopted, using the albuminoid nitrogen in the average sewage at each separate works as a denominator, and the actual oxidised nitrogen in the individual effluents as a numerator, the ratio between the two to exceed a certain agreed figure.

Thus, at Sutton, the mean albuminoid nitrogen, calculated on fifteen samples of crude sewage, was 0·95 parts per 100,000; the oxidised nitrogen in the filtrates from the same sewage was 1·59; the ratio of oxidised to albuminoid nitrogen, 1 : 0·59. All the filtrates were good, and showed no signs of putrescence on keeping. With the one-acre coke filter at the Northern Outfall Works at Barking Creek, a week's working, all the effluents being satisfactory, gave oxidised nitrogen in filtrate 1·1, albuminoid nitrogen in crude sewage 0·423 parts per 100,000; ratio, 1 : 0·38. The septic tank experimental installation at Belleisle, Exeter, gave as a mean of five days, all effluents satisfactory, oxidised nitrogen in filtrates 0·87, albuminoid nitrogen in original sewage 0·25 parts per 100,000; ratio, 1 : 0·29.

If we now consider the case of effluents which are distinctly not satisfactory, and which are invariably putrescent, such as the precipitation effluents at Barking Creek, we find, as the average of a fortnight selected at random, oxidised nitrogen in the effluent 0·2, albuminoid nitrogen in the original sewage 0·41 parts per 100,000; ratio, 1 : 2. (The term "not satisfactory" as regards these effluents must be taken as applying only when the conditions of discharge are those of ordinary towns; in the case of London and the lower Thames they have up to now proved sufficiently good.)

Summarising these results in a table, we get :—

—	Oxidised nitrogen in effluent.	Albuminoid nitrogen in original sewage.	Ratio.
Sutton	1·59	0·95	1 : 0·59
Barking, one-acre filter	1·10	0·42	1 : 0·38
Belleisle, Exeter	0·87	0·25	1 : 0·29
Barking, precipitation	0·20	0·42	1 : 2

The list may be lengthened to any extent, but it will always be found that in effluents which are really satisfactory, and which will pass standards at present in use, the oxidised nitrogen in the effluent will exceed the albuminoid nitrogen in the original sewage by a considerable amount. The suggested standard for sewage works managers to employ might therefore easily be based on this fact. The average albuminoid nitrogen in the particular sewage could be ascertained, and checked by periodical analyses, by the borough analyst; a proportion of oxidised nitrogen, based upon this average figure, could be accepted as evidence of sufficient purification. The works manager could then make daily tests of his final effluent, comparing the oxidised nitrogen found by means of the method already given (page 27) with that in a prepared solution of nitrate of potash of the strength required to meet the particular case.

If to this suggested standard the works manager will add the daily observations on putrescibility and power to support fish life, he will be always in a position to form an accurate judgment regarding the quality of his final effluent, and will get early indications should any portion of his plant become inefficient, through overwork or otherwise.

VII.—THE CARE OF BACTERIAL FILTERS.

A knowledge of the quality of the effluent he is producing is not of very much value to a works manager unless he applies that knowledge in remedying any defects in the installation that may be made apparent by the analysis. But he ought not to leave his filters untended until the falling nitrate or tendency to become putrescent warns him of something wrong. The first thing to remember in looking after the final purification of sewage is that it is a process necessitating the presence of as much air as possible; the second, that with a given quality of sewage a particular filter can only do a certain fixed maximum amount of daily work. Accordingly, bacterial filters must be kept open and loose in texture, and their surfaces must never be allowed to become clogged with finely-divided suspended matters, such as those derived from a septic tank. It is not suggested that these will require removal—anyhow, at frequent intervals—but the surface must be stirred and raked and kept open. Just as it is impossible to use the hoe too much in a kitchen garden, so is it equally impossible to pay too much attention to the surface of a filter. Similar care must be taken regarding the work thrown upon it. Every opportunity should be taken of giving a short rest, especially after any unusually heavy call. Bacterial filter beds have great recuperative powers, but their usefulness may be impaired for months by incautiously overworking them. An excellent example of this may be found in the history of the one-acre coke bed at the Northern Outfall. When work was first started with this, in the autumn of 1893, tank effluent was poured on to it without any regard to its condition or powers, with the result the filter choked, and although the daily quantity passed at the end of three months was only one quarter of that treated at the beginning, the filtrates were foul and stinking, and contained no trace of either nitrous or nitric acid. As a matter of fact, the bed was condemned as a failure. But it was given a prolonged rest, during which time the surface was raked and opened, the interior was frequently examined, and the putrid smell, which was at first most pronounced, gradually wore off, until after three months the whole mass was sweet again. Then, treating with tank effluent was again commenced, but cautiously, increasing the daily dose only as the efficiency of the filter became established. For two years after that the bed was worked regularly, never allowed to become choked or overworked, with the result that no putrescent effluents were ever obtained from it. On another occasion the same bed was, owing to an accident, overrun by a large quantity of sludge. The filter was put out of work, and the surface forked over so as to bury the sludge, and in twenty days regular work was resumed. Both these incidents have been published already more than once, but they are of the greatest value as object-lessons. A bacterial filter evidently may be drowned or may be smothered, but rest and surface disturbance will restore its efficiency, and the surplus matter will disappear under proper conditions just as does the manure dug into a well-tilled garden. The deduction is obvious; avoid choking and overwork, keep the surface always open, and the filter will work for a very long time without showing any signs of impaired efficiency. Daily analysis on the lines suggested in this work will soon show a manager the proper working capacity of each filter, and this should never be exceeded except under the pressure of necessity, and should such arise, it should be followed by rest, partial or complete, according to the circumstances.

The daily testing might conveniently be carried out on the following lines:—

Daily Testing.

Let the samples selected for daily testing be as numerous as time will allow, but always take care to have amongst them one representing the worst conditions; if only one sample can be tested, it 'should certainly be an average representing the strongest rather than the weakest of the day's sewage.

Fill a Nessler cylinder with the effluent and observe its general appearance and colour, and absence or presence of suspended matter. Test its reaction with litmus paper (page 17).

Smell it, with the precautions already given (see *ante*, page 16).

Determine the amounts, approximately, of nitrous and nitric nitrogen (page 26).

Put aside, in a stoppered bottle, a quantity to be daily examined as to odour during seven days, throwing away the corresponding sample taken a week previously. Examine all the bottles by smell, noting whether there is any sign of putrefaction in any of them (page 32).

Nearly empty a bowl or aquarium containing goldfish, and fill up with effluent, previously well aërated by shaking. Note carefully any signs of distress on the part of the fish, such as constantly coming to the surface for air.

Once a week make a determination of the oxygen absorbed from permanganate of potash in four hours.

Record all the observations in a book in tabular form, for convenience of reference ; a useful form of table is shown on page 54.

....Council.

SEWAGE PURIFICATION WORKS.

Weekly Record of Effluents from Bacterial Filter No......   Week ending... ....

	Time.	Appearance.	Odour.	Reaction	Nitrogen.		Notes after seven days' observation.	Oxygen absorbed	Notes.
					Nitrous.	Nitric.			
Monday ...									
Tuesday ...									
Wednesday									
Thursday									
Friday ...									
Saturday ...									

CONVERSION TABLE.

1 grain = ·0648 gramme.
1 gramme = 15·432 grains.
1 lb. = 7000 grains = ·4536 kilogramme.
1 kilogramme = 1000 grammes = 2·205 pounds.
1 yard = 36 inches = ·9144 metre.
1 metre = 39·37 inches = 1·0936 yard.
1 cubic yard = ·7645 cubic metre.
1 cubic metre = 1·308 cubic yard.
1 litre = 1000 cubic centimetres = ·22 gallon.
1 gallon = 4·54 litres.
1 cubic foot water = 6·228 gallons = 28·316 litres.
1 cubic metre water = 220 gallons.

To convert parts per 100,000 into grains per gallon:
Divide by 10 and multiply by 7.

To convert grains per gallon into parts per 100,000:
Divide by 7 and multiply by 10.

For precipitants:

1 grain per gallon = approximately 1¼ cwt. per million gallons treated = 23¼ tons per annum for each million gallons of sewage per diem.

ILLUSTRATIVE ANALYSES OF BACTERIAL FILTRATES.

	Albuminoid Ammonia.	Oxygen absorbed in 4 hours.	Nitric and Nitrous Nitrogen.	Authority.
	Parts per 100,000.			
Leeds (av. of 8 months)	0·167	0·826	1·746	Dibdin and Thudichum.
Sutton (av. of 1 year)	0·084	0·828	3·07	
Belleisle (19 samples)	0·11	0·55	0·864	
Marlboro'. U.S.A.	0·033	0·34	0·56	Kinnicutt.
W. Bromwich (av. of 1 year)	0·068	0·457	0·447	Silvester.
Manchester (expt.)	0·156	1·97	0·66	Report.
Barking (2 years)	0·15	1·15	0·66	L.C.C.
Chipping Norton	0·12	—	0·83	
Glynde	0·43	1·69	1·4	
Taunton	0·2	0·574	0·2	
A country house	0·05	1·2	0·98	

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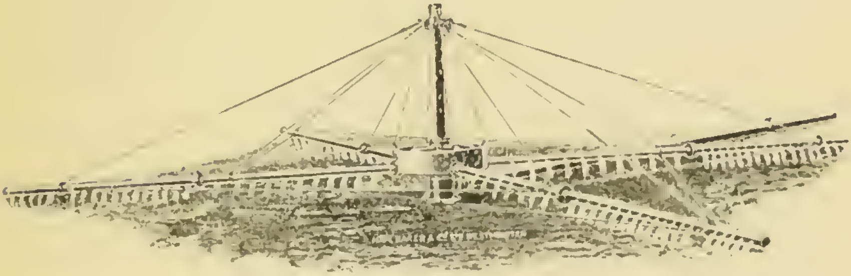

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